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PATENT APPLICATION

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CASE 1-18

TITLE System Comprising Optical Semiconductor Waveguide Device

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

NEW APPLICATION UNDER 37 CFR § 1.53(b)

Enclosed are the following papers relating to the above-named application for patent:

Specification
6 Formal Sheets of drawings
1 Assignment with Cover Sheet
Declaration and Power of Attorney
Information Disclosure Statement

CLAIMS AS FILED				
	NO. FILED	NO. EXTRA	RATE	CALCULATIONS
Total Claims	15 - 20 =	0	x $18 =	$0
Independent Claims	2 - 3 =	0	x $78 =	$0
Multiple Dependent Claims, if applicable			+ $260 =	$0
Basic Fee				$690
			TOTAL FEE	$690

Please file the application and charge **Lucent Technologies Deposit Account No. 12-2325** the amount of $690, to cover the filing fee. Duplicate copies of this letter are enclosed. In the event of non-payment or improper payment of a required fee, the Commissioner is authorized to charge or to credit **Deposit Account No. 12-2325** as required to correct the error.

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"Express Mail" mailing label number: EK552897145US
Date of Deposit June 30, 2000
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Iris F. Thomas
(Printed name of person mailing paper or fee)

Iris F. Thomas
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Please address all correspondence to **Docket Administrator (Room 3C-512), Lucent Technologies Inc., 600 Mountain Avenue, P.O. Box 636, Murray Hill, New Jersey 07974-0636**. However, telephone calls should be made to me at 908-582-3258.

Respectfully,

Scott Rittman
Reg. No. 39010
Attorney for Applicant(s)

Date: June 30, 2000

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SYSTEM COMPRISING OPTICAL SEMICONDUCTOR WAVEGUIDE DEVICE

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to laser devices useful in optical communications systems, particularly wavelength division multiplexing systems.

Discussion of the Related Art

As the use of optical communications continues to increase, the techniques for wavelength generation, selection, and maintenance have become more important. This is particularly the case for wavelength division multiplexing (WDM), in which precise and stable alignment of the source wavelength to a channel of the WDM system is necessary. However, because the emission wavelength of diode lasers tends to vary in response to temperature changes, various measures have been developed in an effort to stabilize emission of the desired source wavelength. One such measure is use of a fiber Bragg grating coupled to a semiconductor laser, where the laser is operated only a gain medium and the grating constitutes one reflective facet of the laser. This device is therefore typically referred to as an external cavity laser. The grating generally reflects only a selected wavelength such that the device lases only at that wavelength. Such an apparatus makes it possible to better ensure that the desired wavelength is emitted.

However, even these Bragg grating devices encounter a variety of stability issues, including thermal stability problems such as a mismatch between the thermal response of the diode versus the Bragg grating. These can significantly interfere with the operation of the laser, particularly where single mode output is desired. See, for example, U.S. Patent No. 5,870,417 to Verdiell et al. (at Col. 2, lines 20-36). In response to these stability problems, Verdiell et al. present numerous - but complex - techniques that attempt to avoid or at least compensate for factors that lead to instability in the output wavelength of laser diode/grating devices, e.g., mode hopping. Simpler, and more commercially feasible, techniques would be preferred.

A separate problem in optical communications is coupling a semiconductor device (e.g., a diode) to a communications fiber - this coupling is difficult and problematic. For

example, a very small displacement of the fiber relative to the semiconductor device output can lead to loss of more than half the light directed at the fiber. For this reason, coupling is typically performed by providing coupling optics between the fiber and the device. These optics can take many forms, including a tapered or conical lens formed or spliced onto the fiber, or a variety of other lens configurations. (Again, see Verdiell et al., supra, at Col. 4, lines 23-54.) Such coupling optics, however, add more complexity, both to the device as well as the overall packaging scheme. And, more significantly, even with these optics, precise alignment is still required.

Thus, improved techniques for overcoming these problems are desired.

SUMMARY OF THE INVENTION

The invention provides an improved optical communication system, particularly suited for so-called short-haul applications, e.g., applications involving transmission over distances less than 100 km, such as metro applications. The system uses an external cavity laser made up of a gain medium that comprises an active region, a beam expanding region, and an antireflective layer, an optical waveguide located adjacent the gain medium, and a Bragg grating integral with or coupled to the optical waveguide. The medium and the optical waveguide, due to the beam expanding region, exhibit a coupling efficiency of at least 40%, advantageously at least 50%, even in the absence of coupling optics, and the laser is configured and operated to emit at least two modes. The system's several advantages and distinctions over existing external cavity laser systems include the following.

First, existing external cavity systems must employ complex temperature compensating apparatus to maintain single mode operation in the face of potential mode-hopping, as discussed in Verdiell et al., supra. By contrast, the laser of the invention avoids the need for such temperature compensation by configuring a short-cavity external cavity laser for multimode operation, generally by selecting a Bragg grating of sufficiently wide bandwidth. It was discovered that multimode operation - 2 to 3 modes is typical - reduced the noise associated with temperature-induced mode-hopping, and thereby provided a more robust, temperature-independent system, with no need for complex

temperature compensation. In fact, without any temperature compensation, bit error rates in the system are less than 10^{-9}, advantageously less than 10^{-12}. (This bit error rate includes a situation, for example, in which a transmitter of a system exhibits a bit error rate greater than 10^{-9} which is corrected to less than 10^{-9} by other hardware or software of the system, e.g., forward error correcting code.) And multimode emission is generally acceptable for short-haul applications, including short-haul applications employing WDM or dense WDM (DWDM).

Second, as discussed above, the process of coupling a gain medium to a fiber tends to be complex and difficult. The gain medium of the invention's external cavity, however, contains a beam expanding region, which allows attainment of a high coupling efficiency (at least 50%) between the medium and the optical waveguide, without the coupling optics that are conventionally used. For example, this high coupling efficiency is attainable even with nothing more than a small air gap between the gain medium and optical waveguide.

Third, because complex and precise coupling optics are not required, packaging of the external cavity laser is relatively cheap and easy. For example, an optical fiber can simply be secured in a v-groove adjacent the gain medium.

Thus, the system of the invention is not only more robust and temperature independent than existing systems, but is also simpler and less expensive to package.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B show an embodiment of an external cavity laser of the system of the invention.

Figs. 2A and 2B show an embodiment of a beam expanding region of an external cavity laser of the system of the invention.

Figs. 3A and 3B show the benefits of the multimode operation of the system of the invention.

Fig. 4 shows the desirable wavelength selectivity of an external cavity laser of the system of the invention.

Fig. 5 shows the mode-hopping that occurs in an embodiment of the invention.

Fig. 6 shows the output of two embodiments of the invention.

Figs. 7A and 7B show the bit error rate provided by an embodiment of the invention, as a function of temperature.

Fig. 8 shows the bit error rate under typical temperature variations in an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

In one embodiment, the laser of the communication system of the invention contains three basic elements, as reflected in Figs. 1A and 1B - a gain medium 12, an optical waveguide 14, and a Bragg grating 16 integral with or coupled to the waveguide 14.

The gain medium 12 contains an active region 18, a beam expander region 20, and an antireflective layer 22 at the surface of the medium 12 adjacent the waveguide 14. One gain medium suitable for the invention is of the type disclosed in co-assigned U.S. Patent No. 5,574,742 to Ben-Michael et al., the disclosure of which is hereby incorporated by reference. Other suitable configurations are disclosed in co-assigned U.S. patent applications serial no. 09/378,032 filed August 20, 1999 (our reference Eng 4-5-1-1-3) serial no. 09/228,218 filed January 11, 1999 (our reference Johnson 6-19-8-1-3), and serial no. 09/561,148 filed April 28, 2000 (our reference Alam 3-6-9-9-10-59), the disclosures of which are hereby incorporated by reference. A short-cavity gain medium, i.e., having a cavity length less than 1 cm is typically suitable.

Figs. 2A and 2B show an embodiment of an active region 30 and beam expander region 31 suitable for use in the invention. As shown in the side view of Fig. 2A, the active region, e.g., a diode laser or optical amplifier, contains a quantum well 33 that generates light when excited or pumped by electrical current. An upper cladding layer 32 is formed over the quantum well 33. Upper and lower guiding layers 35 and 37 are located below the well 33, along with a bottom cladding layer 38. Etch stop layers, illustrated by layers 34 and 36 in Fig. 2A, are typically present to assist the fabrication process. Fig. 2B shows a top view of the active region 30 and beam expander region 31. Variations on this structure are possible. A useful material for the guiding layers 35, 37 is

indium gallium arsenide phosphite (InGaAsP), although a variety of other compound semiconductors, e.g., Group III-IV materials, are also possible. When InGaAsP is used, the etch stop layers are typically formed from indium phosphite (InP), which is highly resistant to etchants that are useful with the InGaAsP. The overall structure is capable of being formed by techniques such as molecular beam epitaxy, vapor phase epitaxy, or metal organic chemical vapor deposition (MOCVD), as discussed in the references cited above.

The beam expanding region 31 expands the size of a beam generated by the active region 30 in two possible ways. First, lateral broadening is possible by making the beam expanding region 31 wider than the active region, as reflected in Fig. 2B. Second, vertical broadening is achieved by the change from two guiding layers 35, 37 to a single guiding layer 37, as the light travels toward the end of the beam expanding region 31. The beam expansion makes coupling of the light beam to an adjacent optical waveguide less problematic, in that misalignment will have a much less significant effect on the coupling efficiency compared to conventional devices.

As shown in Figs. 1A and 1B, the gain medium 10 also contains an antireflective layer 22. The layer 22 prevents the laser chips from lasing off the facets, i.e., prevents Fabry-Perot operation, and thereby makes the gain medium simply an amplifier. The antireflective layer also reduces reflection of the beam as the beam enters the optical waveguide 14. The waveguide is typically an optical fiber, although other waveguides, e.g., planar waveguides, are also possible. The waveguide is placed adjacent to the gain medium, such that the light beam is directed from the beam expanding region, through the antireflective layer, and into the waveguide. As noted above, by using the beam expanding region, it is possible to avoid any coupling optics, e.g., the beam can simply be directed into the polished end of the waveguide, and yet attain high coupling efficiencies, typically at least 40%, advantageously at least 50%. For example, it is possible to simply place or glue an optical fiber into a v-groove adjacent the gain medium. Various other coupling arrangements are suitable. It is also possible to place some index-matching material between the fiber and the gain medium to further reduce reflection and thereby enhance the coupling efficiency.

Once the light enters the waveguide 14, the light is directed to a Bragg grating 16. Typically, the optical waveguide is a fiber, and the Bragg grating is formed in the fiber (i.e., is integral with the fiber), but alternative embodiments are possible, e.g., a planar waveguide having a Bragg grating formed therein, or a waveguide coupled to a separately-formed Bragg grating. The Bragg grating 16 reflects a selected wavelength back toward the gain medium 12, and, due to the presence of a highly reflective layer 24 at the far end of the gain medium, lasing occurs at that selected wavelength. Additional wavelength filters are therefore not needed.

The laser is generally operated at wavelengths ranging from 1.2 to 1.6 μm, which are of primary interest in short-haul applications. Other wavelengths are also possible, however. The gain medium is generally operated by direct modulation, in which the current provided to the medium induces the desired bit rate. Typical bit rates for the system range from 100 MHz to 10 GHz.

The Bragg grating, whether integral with the waveguide or coupled thereto is selected to provide a laser emission of at least two modes, generally several adjacent modes. As discussed above, multimode emission is important to attainment of desirable properties in the overall system. Specifically, complex temperature-compensation apparatus is generally required to maintain a single mode emission, in order to avoid mode-hopping. Multimode emission, however, encounters much less noise due to mode-hopping, and thus allows operation of the external cavity laser without such complex temperature compensation. Specifically, the power fluctuations that occur with power transfers from one mode to another are substantially lessened, relative to single mode operation, because several modes are always lasing, i.e., the average or total power stays constant with the relative power between mode changes. In fact, using this multimode operation, it is possible to achieve a bit error rate of less than 10^{-9}, advantageously less than 10^{-12}, when operating the gain medium without temperature compensation, e.g., at about 2.5 GHz. And the multimode emission is generally suitable for transmission over distances less than 100 km.

A variety of Bragg grating configurations, known in the art, are possible, e.g., chirped gratings or apodized gratings. Selection of a grating that provides sufficient

bandwidth for emission of at least two modes, e.g., a few modes, is within the skill of an ordinary artisan, as is reflected, for example, in Example 1 below, and such gratings are readily available commercially.

The system of the invention useful in a variety of applications. As noted above, the system is particularly useful for short-haul metro applications.

The invention will be further clarified by the following examples, which are intended to be exemplary.

Experimental

Gain media having a cavity length of about 250 μm and containing a beam expanding region of the type discussed above were provided, and configured for direct modulation. The media had a highly reflective coating on the rear facet and an anti-reflective coating having a reflectivity less than 10^{-4} on the front facet. The gain media were mounted on test studs and butt-coupled to fiber Bragg gratings, with an air gap of about 5 μm. The output of these external cavity devices was measured using a Rifocs 578L power meter and characterized using a Hewlett-Packard 7951B optical spectrum analyzer. RF response was measured with a Hewlett-Packard 8593E spectrum analyzer.

Example 1

A modeling experiment was done for two external cavity lasers - one having a grating with a bandwidth of 23 GHz and a second having a grating with a bandwidth of 90 GHz. Both gratings were nominally centered at 1310 nm. Fig. 3A shows a power vs. current plot of the single mode operation of the first modeled laser. The discontinuity due to a mode hop is apparent, and such a discontinuity would introduce significant bit errors in such devices. Fig. 3B shows the power vs. current plot for the second, multimode device, which has a much smoother curve indicative of a more robust, temperature-insensitive device.

Example 2

An external cavity laser was configured for multimode operation by use of a Bragg grating having a FWHM of 90 GHz, again with the Bragg grating centered at a wavelength of 1310 nm. Fig. 4 shows the power vs. current plot for the device at 33°C.

The relatively smooth transition from mode to mode, relative to what would be expected for single mode operation, is shown.

Fig. 5 shows the mode hops as a function of temperature and time. Specifically, as the temperature varied with time, the operative modes shifted while maintaining the multimode operation.

Example 3

Two external cavity lasers were configured for multimode operation, by use of a Bragg grating having a FWHM of 90 GHz. The first had a Bragg grating centered at a wavelength of 1309.3 with a $\Delta\lambda$ of 0.325 nm, and the second had a Bragg grating centered at a wavelength of 1316.3 with a $\Delta\lambda$ of 0.438 nm. Each device emitted about 3 modes. Fig. 6 shows the output of both devices when the gain medium was modulated at about 2.5 GHz at ambient temperature. The desirable suppression of non-desired Fabry-Perot modes is apparent.

Example 4

An experiment to determine the temperature sensitivity of a device of the invention, by monitoring bit error rate, was performed. The laser device was identical to that used in Example 2. High speed operation up to about 2.5 GHz was characterized by an Anritsu MP1662A digital data analyzer. The laser device was mounted on a thermal electric cooler, and the bit error rate (BER) through 32 km of fiber was measured as a function of temperature, using the cooler to make the desired temperature changes. The bias current was adjusted to maintain substantially constant power at the receiver for each temperature at which the BER was measured. The results are shown in Fig. 7A. Fig. 7B shows the same measurement, but over a smaller temperature scale. As can be seen from Fig. 7B, temperature variations of a few degrees had substantially no effect on BER. Note that this experiment reflects a worse-case measurement, given that only the chip was heated, while the remainder of the device remained at room temperature.

Fig. 8 shows the BER during operation of the laser in an uncooled mode, i.e., with no applied temperature changes, over several days through 32 km of fiber, with the laser

being run at about 2.5 GHz. It is apparent that the room temperature variations had very little effect on BER.

Other embodiments of the invention will be apparent to those skilled in the art from consideration of the specification and practice of the invention disclosed herein.

What is claimed is:

1. An optical communication system comprising an external cavity laser that comprises:

a gain medium comprising an active region, a beam expanding region, and an antireflective layer on a first surface of the gain medium;

an optical waveguide located adjacent the gain medium such that at least a portion of the electromagnetic energy generated by the active region passes through the beam expanding region and through the antireflective layer into the optical waveguide; and

a Bragg grating integral with or coupled to the optical waveguide,

wherein the medium and the optical waveguide exhibit a coupling efficiency of at least 40% with or without the presence of coupling optics located between the gain medium and the optical waveguide, and

wherein the laser is configured and operated to provide a multimode output of at least two modes.

2. The system of claim 1, wherein the coupling efficiency is at least 40% with or without the presence of coupling optics located between the gain medium and the optical waveguide.

3. The system of claim 1, wherein the gain medium comprises a cavity less than 1 cm in length.

4. The system of claim 1, wherein the length of the system is less than 100 km.

5. The system of claim 1, wherein the laser is operated by direct modulation.

6. The system of claim 1, wherein the bit error rate of the system is less than 10^{-9}.

7. The system of claim 6, wherein the bit error rate of the system is less than 10^{-12}.

8. The system of claim 1, wherein the laser is operated at 2.5 GHz or greater.

9. The system of claim 1, wherein the laser is operated in the absence of a temperature-compensating apparatus.

10. The system of claim 1, wherein the gain medium and optical waveguide are coupled in the absence of coupling optics.

11. An optical communication system comprising an external cavity laser that comprises:

a gain medium comprising an active region, a beam expanding region, and an antireflective layer on a first surface of the gain medium;

an optical waveguide located adjacent the gain medium such that at least a portion of the electromagnetic energy generated by the active region passes through the beam expanding region and through the antireflective layer into the optical waveguide; and

a Bragg grating integral with or coupled to the optical waveguide,

wherein the medium and the optical waveguide exhibit a coupling efficiency of at least 40% in the absence of coupling optics located between the gain medium and the optical waveguide,

wherein the laser is configured and operated to provide a multimode output of at least two modes,

wherein the laser is operated by direct modulation,

wherein the laser is operated in the absence of a temperature-compensating apparatus,

wherein the gain medium comprises a cavity less than 1 cm in length, and

wherein the length of the system is less than 100 km.

12. The system of claim 11, wherein the coupling efficiency is at least 40% with or without the presence of coupling optics located between the gain medium and the optical waveguide.

13. The system of claim 11, wherein the bit error rate of the system is less than 10^{-9}.

14. The system of claim 13, wherein the bit error rate of the system is less than 10^{-12}.

15. The system of claim 13, wherein the laser is operated at 2.5 GHz or greater

Abstract of the Disclosure

An improved optical communication system is provided, the system particularly suited for so-called short-haul applications, e.g., applications involving transmission over distances less than 100 km, such as metro applications. The system uses an external cavity laser made up of a gain medium that comprises an active region, a beam expanding region, and an antireflective layer, an optical waveguide located adjacent the gain medium, and a Bragg grating integral with or coupled to the optical waveguide. The medium and the optical waveguide, due to the beam expanding region, exhibit a coupling efficiency of at least 40%, advantageously at least 50%, even in the absence of coupling optics, and the laser is configured and operated to emit at least two modes.

FIG. 1A

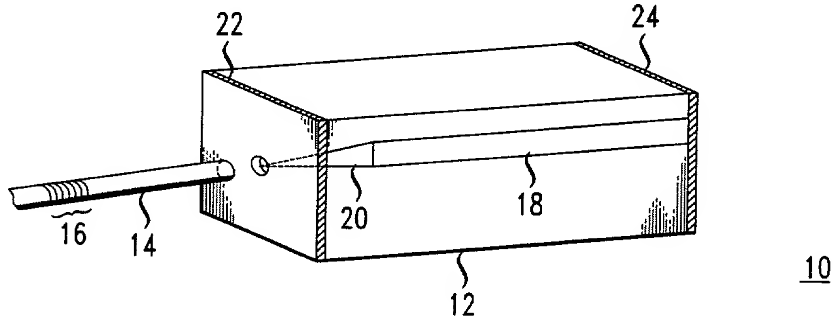


FIG. 1B

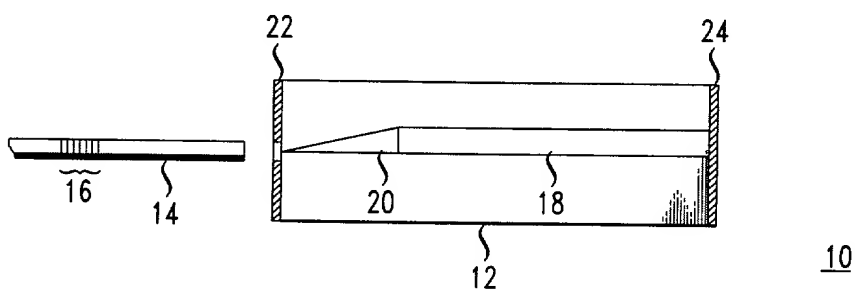


FIG. 2A

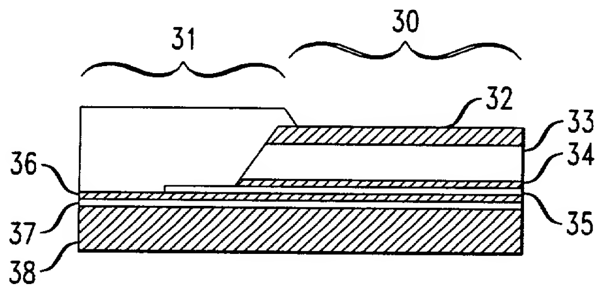


FIG. 2B

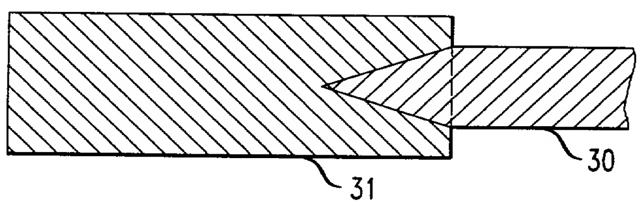


FIG. 3A

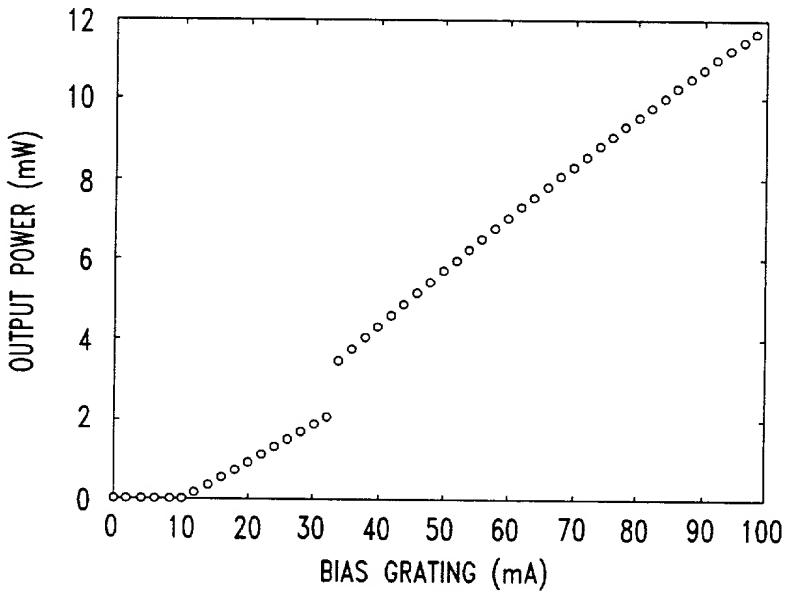
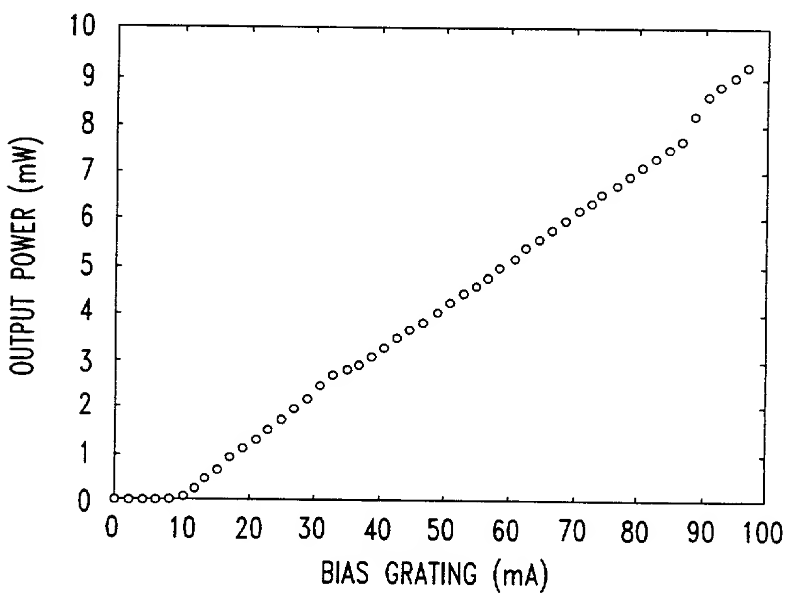

OUTPUT POWER (mW)
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
90
100
BIAS GRATING (mA)

FIG. 3B


OUTPUT POWER (mW)
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9
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7
6
5
4
3
2
1
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0
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20
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40
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60
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90
100
BIAS GRATING (mA)

FIG. 4

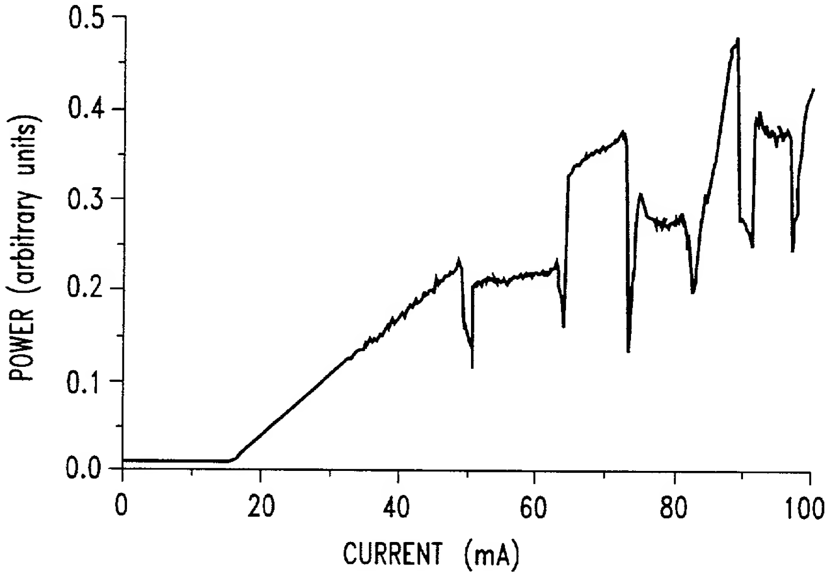

0.5
0.4
0.3
0.2
0.1
0.0
POWER (arbitrary units)
0
20
40
60
80
100
CURRENT (mA)

FIG. 5

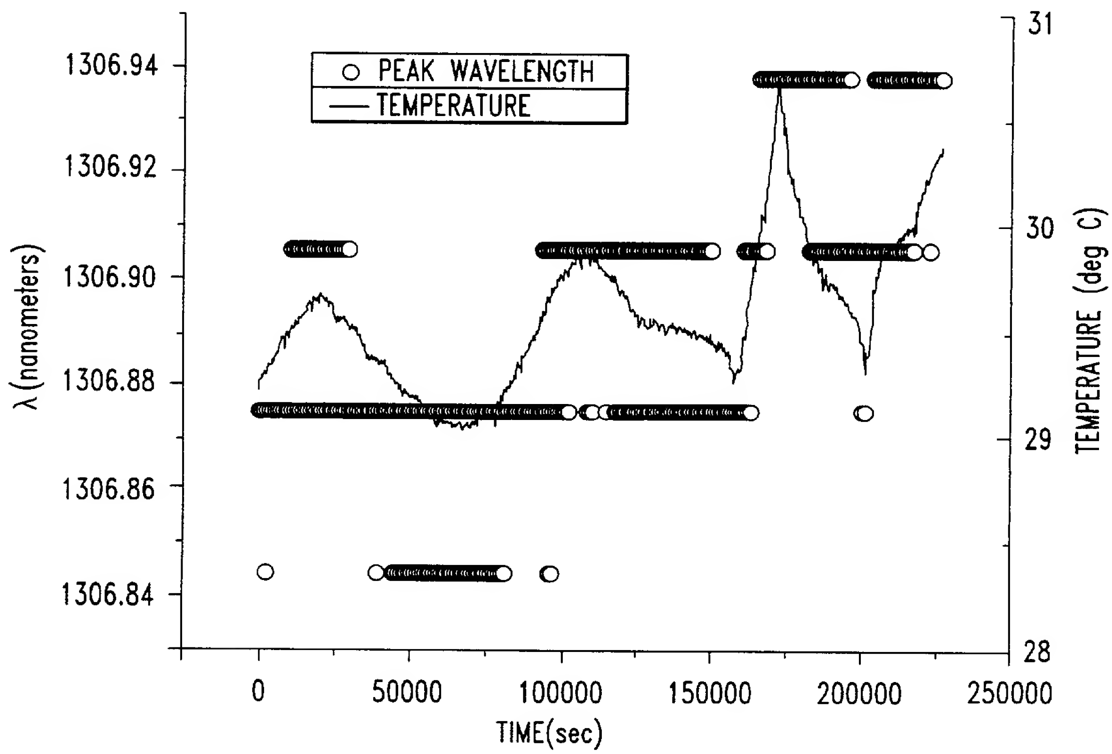

PEAK WAVELENGTH
TEMPERATURE
1306.94
1306.92
1306.90
1306.88
1306.86
1306.84
λ (nanometers)
31
30
29
28
TEMPERATURE (deg C)
0
50000
100000
150000
200000
250000
TIME(sec)

FIG. 6

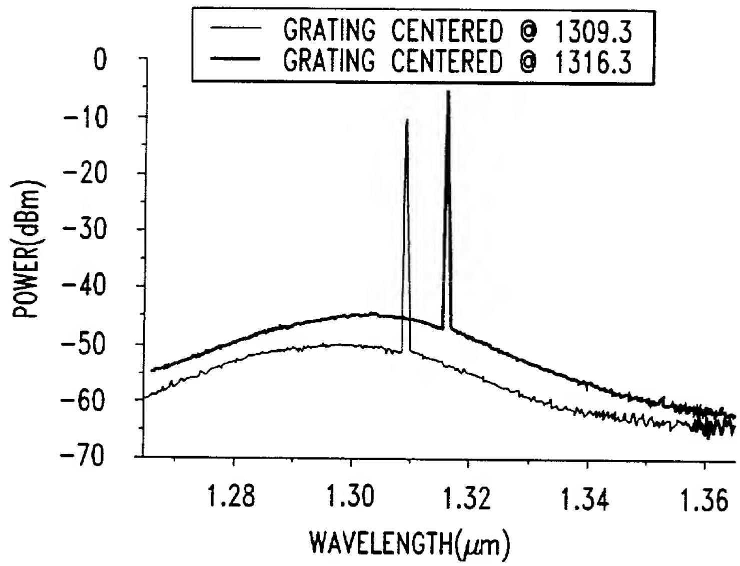

GRATING CENTERED @ 1309.3
GRATING CENTERED @ 1316.3
0
-10
-20
-30
-40
-50
-60
-70
POWER(dBm)
1.28
1.30
1.32
1.34
1.36
WAVELENGTH(μm)

FIG. 8

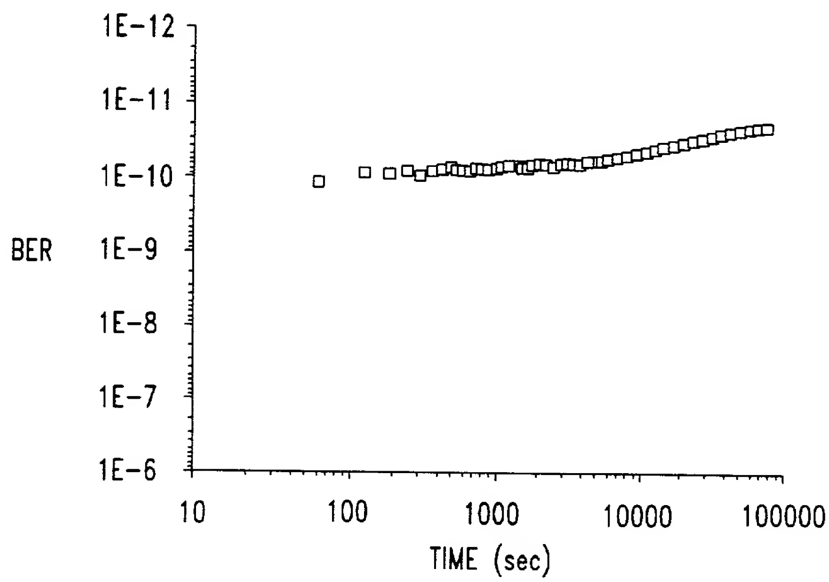

1E-12
1E-11
1E-10
BER
1E-9
1E-8
1E-7
1E-6
10
100
1000
10000
100000
TIME (sec)

FIG. 7A

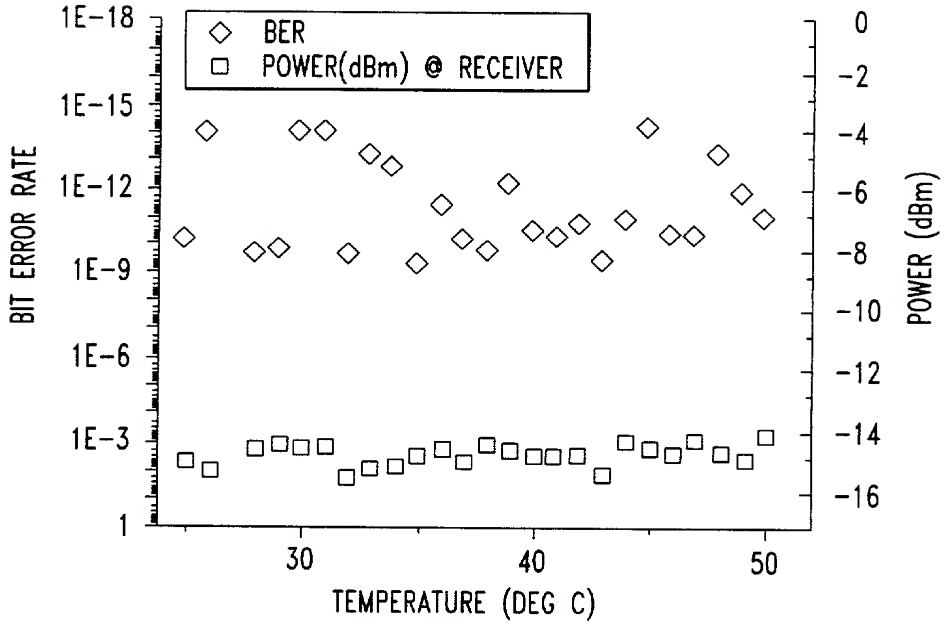
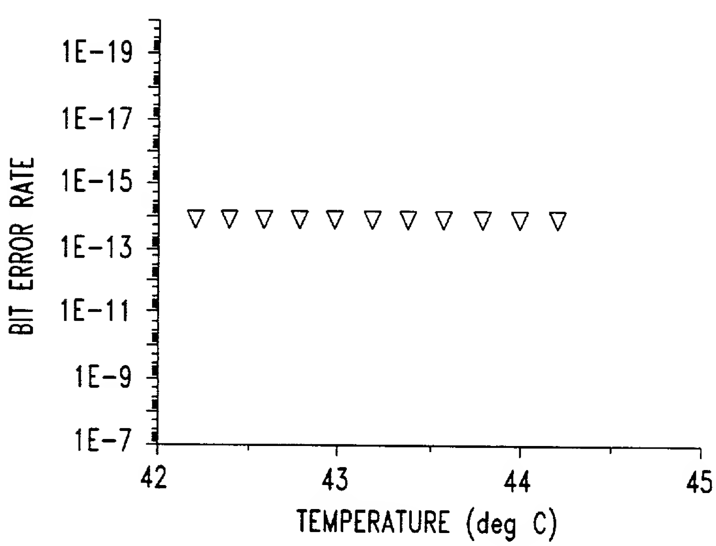

BER
POWER(dBm) @ RECEIVER
BIT ERROR RATE
1E-18
1E-15
1E-12
1E-9
1E-6
1E-3
1
0
-2
-4
-6
-8
-10
-12
-14
-16
POWER (dBm)
30
40
50
TEMPERATURE (DEG C)

FIG. 7B


BIT ERROR RATE
1E-19
1E-17
1E-15
1E-13
1E-11
1E-9
1E-7
42
43
44
45
TEMPERATURE (deg C)

IN THE UNITED STATES
PATENT AND TRADEMARK OFFICE

Declaration and Power of Attorney

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am an original, first and joint inventor of the subject matter which is claimed and for which a patent is sought on the invention entitled **System Comprising Optical Semiconductor Waveguide Device** the specification of which is attached hereto.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by an amendment, if any, specifically referred to in this oath or declaration.

I acknowledge the duty to disclose all information known to me which is material to patentability as defined in Title 37, Code of Federal Regulations, 1.56.

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

None

I hereby claim the benefit under Title 35, United States Code, 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, 112, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in Title 37, Code of Federal Regulations, 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application:

None

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

I hereby appoint the following attorney(s) with full power of substitution and revocation, to prosecute said application, to make alterations and amendments therein, to receive the patent, and to transact all business in the Patent and Trademark Office connected therewith:

Thomas J. Bean	(Reg. No. 44528)
Lester H. Birnbaum	(Reg. No. 25830)
Richard J. Botos	(Reg. No. 32016)
Jeffery J. Brosemer	(Reg. No. 36096)
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